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THE HYDROGEN-PEROXIDE ROCKET REACTION-CONTROL SYSTEM

FOR THE X-1B RESEARCH AIRPLANE

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SUMMARY

A hydrogen-peroxide rocket reaction-control system was designed and fabricated for the X-1B research airplane. This system was developed as a means of providing control at high altitudes in regions of low dynamic pressure. The system, which was designed to operate at zero normal acceleration and in an extremely low-temperature environment, consists of a storage vessel, pressurization system, flow-control system, and rocket units. A control of the on-off type was used, with which the rockets were operated at fixed thrust levels of from 20 to 40 pounds.

Ground tests were conducted on a simulator and on the X-1B airplane. These tests demonstrated satisfactory operating characteristics. Control-system response was primarily affected by the lag of the control valves, and the importance of low valve lag was demonstrated.

INTRODUCTION

As the high-altitude capabilities of high-performance jet and rocket aircraft are exploited, ballistic flight paths with dynamic pressures approaching zero will be encountered; thus, new means of aircraft control will be required. One means of control that has received much consideration utilizes the thrust from rockets or jets positioned to produce the required control torques.

To provide information pertinent to the application of such controls to piloted-aircraft control systems, the NASA High-Speed Flight Station, at Edwards, Calif., conducted simulator and ground tests of various types of jet controls. Results of the simulator studies were reported in references 1 and 2. From these studies it was concluded that a simple fixed-thrust on-off control system would be adequate for certain applications. Therefore, a program was initiated to flight test a fixed-thrust on-off jet-control system in the X-1B research airplane. After the design, fabrication, and installation of the system in the airplane were completed, ground tests were conducted. However, airplane operational problems made it necessary to terminate the program before a complete flight evaluation of the controls could be made. The project was then transferred to another aircraft.

This paper outlines some of the unique problems encountered during the design and testing of the jet-control system, discusses the design and fabrication of the system, and presents data pertinent to the system performance characteristics.

GENERAL DESIGN CONSIDERATIONS

The design of the reaction-control system was based upon the requirement that the pilot be provided with a system for controlling, in a full-on or full-off manner, a specified amount of torque about each axis. Also affecting the design were the environmental and operational conditions peculiar to the X-1B airplane.

The thrust requirements were established by the location of thrust-producing units for the specified torques. For optimum control, thrust should be available immediately upon demand. A brief investigation of thrust-producing methods indicated that rocket units which utilized 90-percent hydrogen peroxide (H_2O_2) as the fuel would be suitable and, also, that rockets of the desired thrust ranges were available. In addition, since H_2O_2 was aboard the airplane to power the airplane propellant turbopump, some of the existing system could be utilized for the reaction controls. However, special consideration had to be given to the high freezing temperature (about 18° F) of H_2O_2 and to the incompatibility of H_2O_2 with many materials. Some of the physical properties of H_2O_2 are presented in reference 3.

Since H_2O_2 in combination with a suitable catalyst can be used as a monopropellant, no ignition was necessary and the only control required was of propellant flow. An electrically actuated flow-control system, with a minimum of moving parts for ease of installation and maintenance, was selected.

The reaction-control system was adapted to the X-1B turbopump H_2O_2 system and to the existing airplane-operating procedure. Inasmuch as the X-1B is a rocket-powered airplane, which is air-launched at an altitude of about 30,000 feet from a B-29 mother airplane, a check of reaction-control-system operation was required before launch. Also, it was necessary to provide for jettisoning the H_2O_2 in the event of emergency, either while the X-1B was attached to the B-29 or at any time after launch.

Because of the time required for the B-29 to climb to launch altitude, the X-1B was subjected to temperatures near -40° F for periods up to 40 minutes. Also, an ambient air temperature of -100° F at operating altitudes was not uncommon. These temperatures, in combination with the high freezing temperature of H_2O_2, necessitated precautions to prevent freezing of H_2O_2 in the system.

It was necessary that the system be operable at positive, zero, and negative vertical accelerations. Since some of these conditions produce problems of unporting of liquid-supply tanks, provision for the expulsion of H_2O_2 under any acceleration condition was necessary.

DESCRIPTION OF EQUIPMENT AND METHOD OF OPERATION

Equipment

The reaction-control system is composed of a fuel-storage vessel, a pressurizing system, a flow-control system, and rocket units. Figure 1 shows the location of these major components and the associated plumbing and electrical wiring within the X-1B airplane. A photograph of the X-1B showing the position of the rocket nozzles is presented in figure 2. A detailed schematic diagram of the complete system is presented in figure 3.

Storage vessel.- The storage vessel was designed for ease of fabrication. Because fewer development problems were anticipated with a piston-type expulsion system, a system of this type was chosen in preference to a bladder type. The vessel capacity, 2.4 gallons, was consistent with the estimated fuel requirements (30-sec continuous thrust for each axis) and with the space limitations in the X-1B. The storage vessel was constructed of type 321 stainless steel. A cutaway sketch of the vessel is shown in figure 4, and photographs of the major components are shown in figure 5(a). Hydrogen peroxide is expelled from the vessel by pressurizing one side of a moving piston, which provides positive expulsion under any acceleration condition. A tube through the center of the tank is used for piston alinement and as the tank-outlet line. The piston is guided on the outlet tube by a Teflon bushing and is sealed from the tube and vessel wall by two Viton O-rings.

The storage vessel is located adjacent to the aircraft liquid-oxygen tank. The low temperature of the tank (-273° F) made heating and insulation of the storage vessel necessary. The vessel is heated with an electric heater which furnishes 1 watt per square inch of external surface. The heater element is embedded in plastic and cemented onto two aluminum half-cylinders (fig. 5(b)) which surround the storage vessel. The vessel and heater are enclosed in a Fiberglas insulating blanket, and a thermostat is used to maintain a temperature of 80° F ±10°. Power for the heater is furnished by the B-29 mother airplane. The time interval from launch to operating altitude is such that the H_2O_2 remains above freezing temperature after power from the B-29 is disconnected at launch.

The H_2O_2 lines from the tank to the system components are constructed of 3/8-inch O.D. 300-series stainless-steel tubing. Fiberglas blankets are used to insulate all lines exposed to low temperatures.

Pressurization system.- The reaction-control system is pressurized by the nitrogen-supply system of the X-1B airplane. The H_2O_2 storage vessel is pressurized to 415 psi through a three-way solenoid valve (fig. 3, no. 2) which pressurizes or vents the gas side of the system. A frangible disk (fig. 3, no. 4) in the hydrogen-peroxide system serves as a safety valve in the event of excessive pressure buildup.

A valve (fig. 3, no. 10) is included in the system to provide for jettisoning the hydrogen peroxide. This valve operates simultaneously with operation of the H_2O_2 jettison valve of the airplane propellant system.

Flow-control system.- The pilot controls the rockets by means of a small stick that protrudes from the instrument panel, as shown in figure 6. The stick can be rotated about three axes; this motion operates microswitches that shuttle appropriate solenoid valves (fig. 3, no. 8) to admit H_2O_2 to the rockets.

Initially, two-way-type solenoid valves were used. These valves allowed H_2O_2 to flow to the rockets whenever the system was pressurized. One outlet of the valve maintained a flow of H_2O_2 to the rockets to preheat the catalyst bed, which improves thrust response, and to bleed H_2O_2 continuously through the system to reduce the possibility of freezing. A separate outlet supplied the main flow of H_2O_2 to the rockets. A second type of valve was used later in the program in an effort to reduce the time lag of valve operation, as is discussed in a subsequent section. This valve contained only one outlet, for main-propellent flow, and the continuous preheat bleed was eliminated. Preheat was accomplished by frequent operation of the individual rockets.

Rocket units.- Shown in figure 7(a) are the rocket units procured from Bell Aircraft Corp. The rockets could be operated over a thrust range from about 5 pounds to 75 pounds. Thrust is developed from the decomposition of H_2O_2 passing through a silver-screen catalyst inside the chamber. The catalyst bed consists of a series of silver-coated and stainless-steel screens having various mesh, as shown in figures 7(a) and 7(b).

The exit nozzle is normal to the plane of the catalyst screen chamber to form a more compact installation package. The exit nozzles were installed approximately flush with the fuselage line or wing-tip-pod contour, and an O-ring sealed the area between the nozzle and the fuselage, or pod.

The rockets were located on the X-1B to provide the largest possible moment arm, and the thrust of each unit was adjusted to provide the required torques as determined by the tests reported in reference 1. The various locations of the rocket units shown in figure 1 resulted in the following values of rocket thrust:

	Thrust, lb
Left and right roll, (each)	20
Left and right yaw, (each)	42
Pitchup	25
Pitch-down	40

Thrust is regulated by an orifice in each valve which provides the correct flow of H_2O_2 to the individual rockets. These orifices range from 0.055 inch to 0.081 inch in diameter.

Closeup photographs of the roll-rocket installation and pitchup rocket installation are shown in figures 8 and 9, respectively.

Instrumentation.- Standard aircraft-recording instrumentation was used to record rocket-chamber pressures and control-stick actuation. Storage-vessel pressure was indicated on a gage on the pilot's instrument panel and also telemetered to a ground station. A pressure transducer, attached to a line from the storage vessel, transmitted this pressure to the pilot's indicator. A small stainless-steel cylinder and piston, shown in figure 10, were inserted between the H_2O_2 line and the transducer to separate the H_2O_2 from the remainder of the system and reduce the possibility of H_2O_2 contamination and explosion. Pressure is transmitted from the piston to the flurolube, a lubricant commonly used in H_2O_2 systems, then to the transducer. Storage-vessel pressure was also measured by strain gages attached to the head of the vessel and was telemetered to the ground station.

So that each rocket could be checked for satisfactory operation prior to release of the X-1B from the B-29 mother ship, individual rocket temperatures were measured by thermocouples attached to each rocket body (fig. 7(a)). The decomposition of the H_2O_2 produces high-temperature gases (about 1,300° F), and the temperature of the rocket rises rapidly whenever the rockets are operated. The output from the thermocouples was indicated on a gage monitored by an operator in the B-29 during the preheat operation.

Method of Operation

Servicing.- Hydrogen peroxide is displaced under 9-psi pressure from a servicing vehicle into the aircraft storage vessel through the fill connection (fig. 3, no. 5). The fluid displaces the piston to the top of the vessel. When the gas ceases to flow from the normally vented port of the pressure and vent valve (fig. 3, no. 2), the piston has reached maximum travel and the vessel is full. The shutoff valve (fig. 3, no. 3) is closed during this operation to prevent H_2O_2 from entering the unheated portion of the system. All lines downstream from the shutoff valve remained free from H_2O_2 until preheat was initiated. This prevented chilling and possible freezing of any H_2O_2 in the lines during the B-29 climb to launch altitude. The external sources of nitrogen and H_2O_2 are removed after the filling process is completed.

Preheating.- When the preheat position is selected, H_2O_2 from the airplane propellant system is supplied to the reaction-control system through the normally closed crossover valve (fig. 3, no. 6). This permits the airplane system, which has a large capacity, to provide the H_2O_2 requirements for preheating the system during the initial portion of each flight.

Pressurizing.- When switch A (fig. 3) is placed in the pressurize position, the pressure and vent valve (fig. 3, no. 2) opens and the storage vessel is pressurized by 415 psi of nitrogen. Also, the crossover valve (fig. 3, no. 6) is deactuated, which closes off the airplane propellant H_2O_2 supply, and the system shutoff valve (fig. 3, no. 3) is opened. The system is now ready for operation.

Jettisoning.- The H_2O_2 may be jettisoned by pressurizing the system and operating the airplane jettison switch to open the jettison valve (fig. 3, no. 10).

OPERATING CHARACTERISTICS

Ground tests were made on the completely installed control system in the airplane and also on a ground test rig. This test rig (described in ref. 1), although initially constructed to conduct other reaction-control studies, was available for the H_2O_2 system-development studies.

The installation of the complete X-1B reaction-control system on the test rig was similar to the installation of the system in the airplane. Various components and modifications were tested on this rig before the system was installed in the airplane. For this purpose, the rig incorporated instrumentation to record individual rocket-chamber pressures, control-stick actuation, and storage-vessel pressure.

Response Characteristics

Tests were made to determine the response of the system to short, pulse-type control inputs, which were shown in reference 1 to be the normal technique used by pilots when operating on-off controls. Most of these tests were made on the ground test rig to utilize the more extensive instrumentation available.

A sample oscillograph record from a typical test run is shown in figure 11. As indicated, the total lag from the time the pilot actuates the control stick until full thrust is developed can be broken down into several parts. The first, valve lag, consists of the time delay from the transmission of the electric signal to the solenoid until the valve begins to open (as indicated by a drop in supply pressure). Another delay, flow lag, is indicated from the time the valve opens and H_2O_2 flows to the rocket until the chamber pressure begins to rise. Finally, there is a finite time, thrust lag, for the chamber pressure to attain the full thrust value. Similar lags are also apparent at thrust termination.

Figure 12 shows measurements of these lags and the total lag for one valve-rocket combination (valve A) at thrust levels from 6 to 68 pounds. For the thrust-on condition, the total lag is higher at the lower thrust levels because of an increase in thrust-buildup time; the data indicate total lags of about 0.2 second for the X-1B design thrust levels. For the thrust-off condition both thrust lag and flow lag remain small, but the valve-closing lag is considerably longer than the opening lag; consequently, total lag would be about 0.35 second for the X-1B thrust levels.

To expedite early experience with the reaction-control system, type A valves were first installed although it was apparent that the system would have rather poor response characteristics because of the large valve lag. Simultaneously, tests were initiated to examine the lag characteristics of other types of valves. The results of comparative tests for the type A valve and for a second valve, type B, are shown in figure 13. The vertical line indicates the range of lag measurements for six valves of each type. The lags for valve B are significantly lower, which can be attributed to faster acceleration of the poppet, because of its smaller mass, and to lower sliding friction, because of fewer seals, as shown in figures 14(a) and 14(b).

The importance of low valve lag is illustrated in figure 15, which compares system response for valve A and valve B for comparable thrust levels. The difference in response to two short control inputs is apparent; the system with the largest lag fails to respond to the two separate inputs and produces continuous thrust, whereas the system with low valve lag produces control of nearly the same duration as the control input. Type B valves were selected for the final X-1B system.

It was believed that long lengths of line from the valve to the rocket unit could increase the lag appreciably. However, for 3/8-inch or 1/2-inch O.D. lines from 6 inches to 3 feet in length, once the system was primed by the preheat operation, there was little difference in the thrust-on lag characteristics. The lag at thrust-off was only 0.05 second greater with 3-foot lines than with 6-inch lines.

Specific Impulse

The manufacturer's calibration runs showed the specific-impulse levels of the rockets to be from 104 lb-sec/lb at 20 pounds thrust to 118 lb-sec/lb at 42 pounds thrust. These values were measured during calibration runs at constant thrust.

The method used to determine specific impulse for the present tests was based on calculations of total thrust during a run to fuel exhaustion for the known vessel capacity. Since preheat required 0.05 lb/sec of hydrogen peroxide, amounting to approximately one-half vessel capacity for a normal 5-minute test, it was difficult to determine accurately the specific impulse for the rocket-on test period. However, several test runs for the pulse-type operation shown in figure 11 indicated the average specific impulse of the system to be slightly less than 100. Thus, it appears that about 10 percent more fuel is required when the rockets are fired in short bursts than at constant thrust.

Problem Areas and Difficulties

As previously noted, some "off-the-shelf" three-way solenoid valves were used in an effort to expedite early experience with the reaction-control system. These valves were of 2024 ST anodized aluminum with stainless-steel poppets and standard AN 6227-type O-rings. In the presence of hydrogen peroxide this combination gave considerable difficulty. Electrolytic action took place between the stainless steel and the aluminum, and the O-ring material reacted with the hydrogen peroxide in a manner which accelerated the corrosion of the aluminum in the O-ring grooves. Early tests were accomplished, however, by frequent disassembly of the valve and replacement of the O-rings. Another type of valve, with a 5052 SO aluminum body, Viton material O-rings, and stainless-steel poppets, gave much better service and extended the period between disassembly and cleaning. The valve configuration used during the last phases of testing had a type 321/347 stainless-steel body, Teflon chevron rings, and type 316 stainless-steel poppets. Experience indicates that this configuration is satisfactory.

After each test run, purging the system of as much H_2O_2 as possible is necessary to prevent residual H_2O_2 from causing corrosion. Purging is normally accomplished by blowing out the system with a high flow of nitrogen gas. In the system tested, purging was a problem because the small orifices (used to control H_2O_2 flow) restricted the flow of the nitrogen gas. Therefore, it was necessary to include purge outlets (fig. 3, no. 11) in the system to bypass the orifices.

CONCLUDING REMARKS

In use, the hydrogen-peroxide rocket reaction-control system tested demonstrated satisfactory operating characteristics. Use of a piston-type pressurization system and of either continuous or intermittent preheat proved satisfactory. The steps taken to prevent hydrogen peroxide from freezing were adequate. Use of solenoid valves with opening and closing time lags of about 0.05 second in combination with rocket thrust-buildup lags of about 0.1 second and rocket thrust-termination lags of 0.05 second resulted in good system-response characteristics. Operation of the rocket units as a one-thrust level, on-off type was satisfactory, but resulted in approximately a 10-percent loss in specific impulse in comparison with continuous-thrust operation.

High-Speed Flight Station,
National Aeronautics and Space Administration,
Edwards, Calif., September 1, 1959.

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2. Stillwell, Wendell H., and Drake, Hubert M.: Simulator Studies of Jet Reaction Controls for Use at High Altitude. NACA RM H58G18a, 1958.

3. Dierdorff, Lee H., Jr.: Hydrogen Peroxide Physical Properties Data Book. Bull. No. 67, second ed., Buffalo Electro-Chemical Co., Inc., 1955.

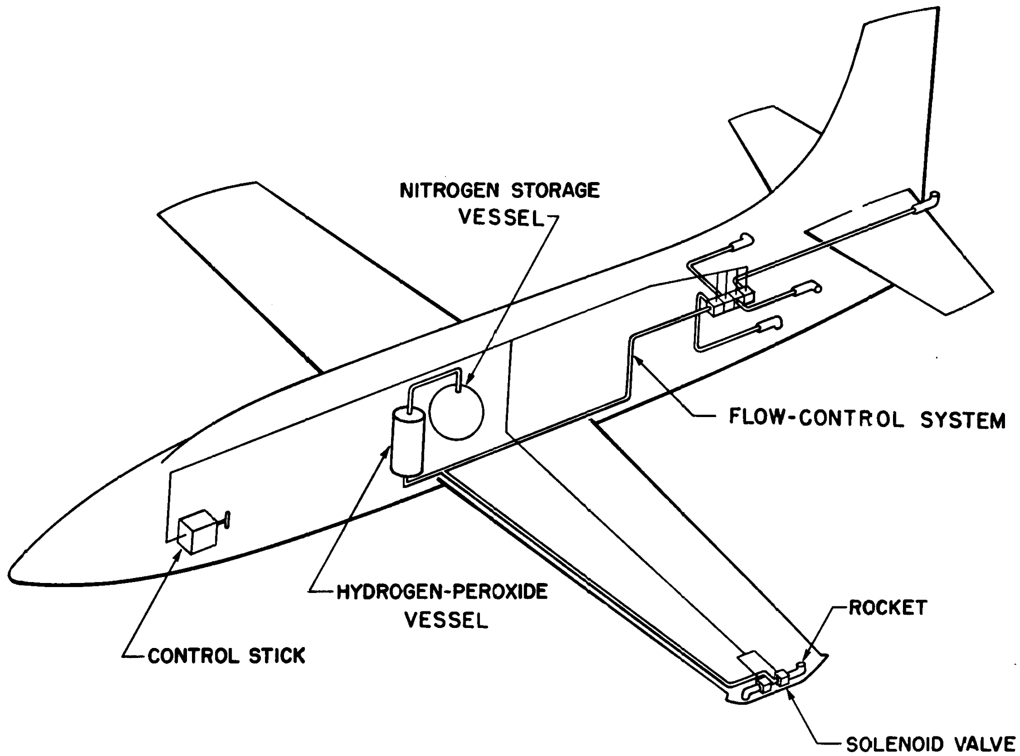

Figure 1.- Sketch of X-1B hydrogen-peroxide rocket reaction-control system showing location of major system components.

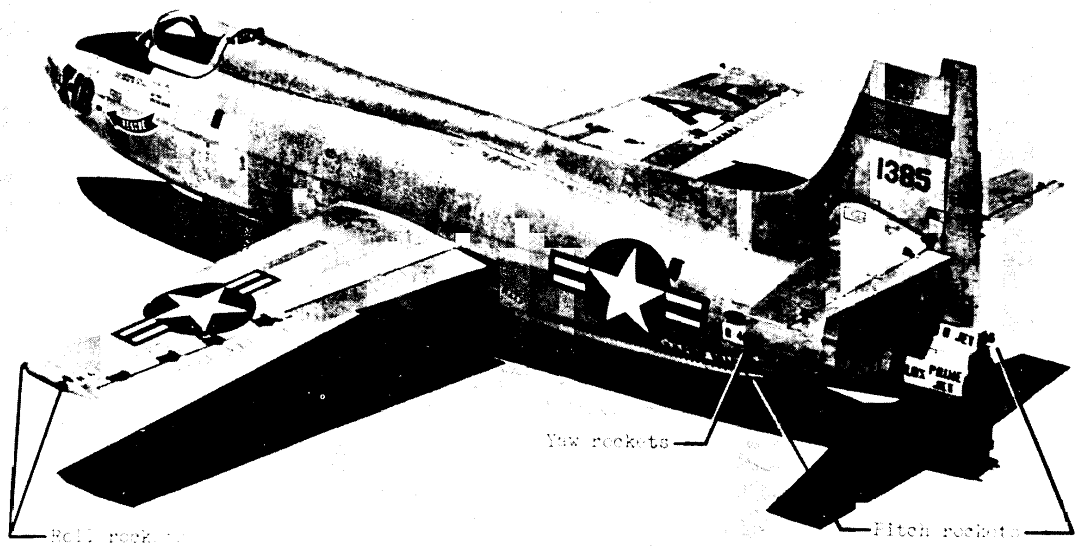

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Figure 2.- Photograph of X-1B airplane showing location of reaction-control rockets.

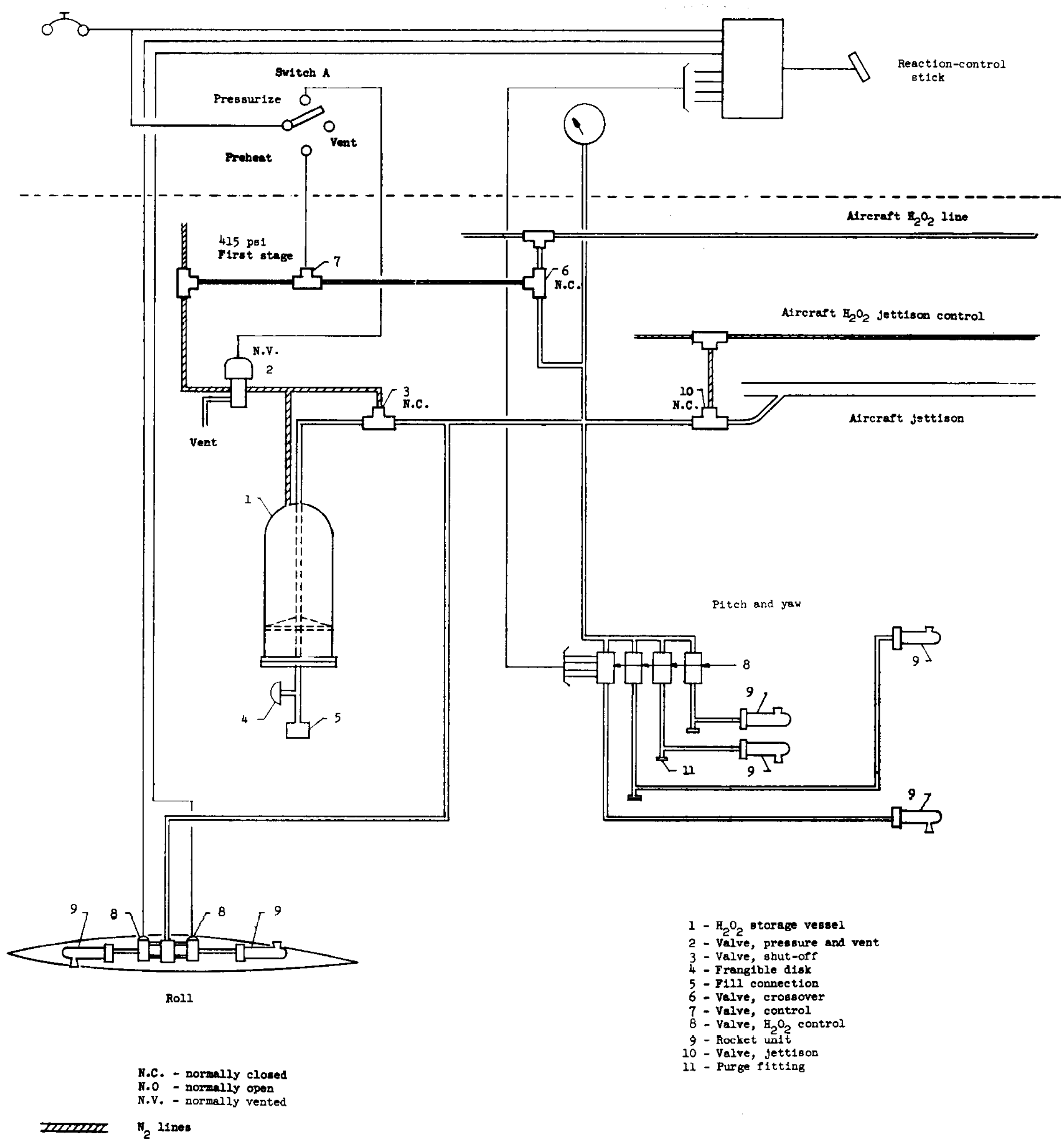


Figure 3.- Schematic diagram of X-1B reaction-control system.

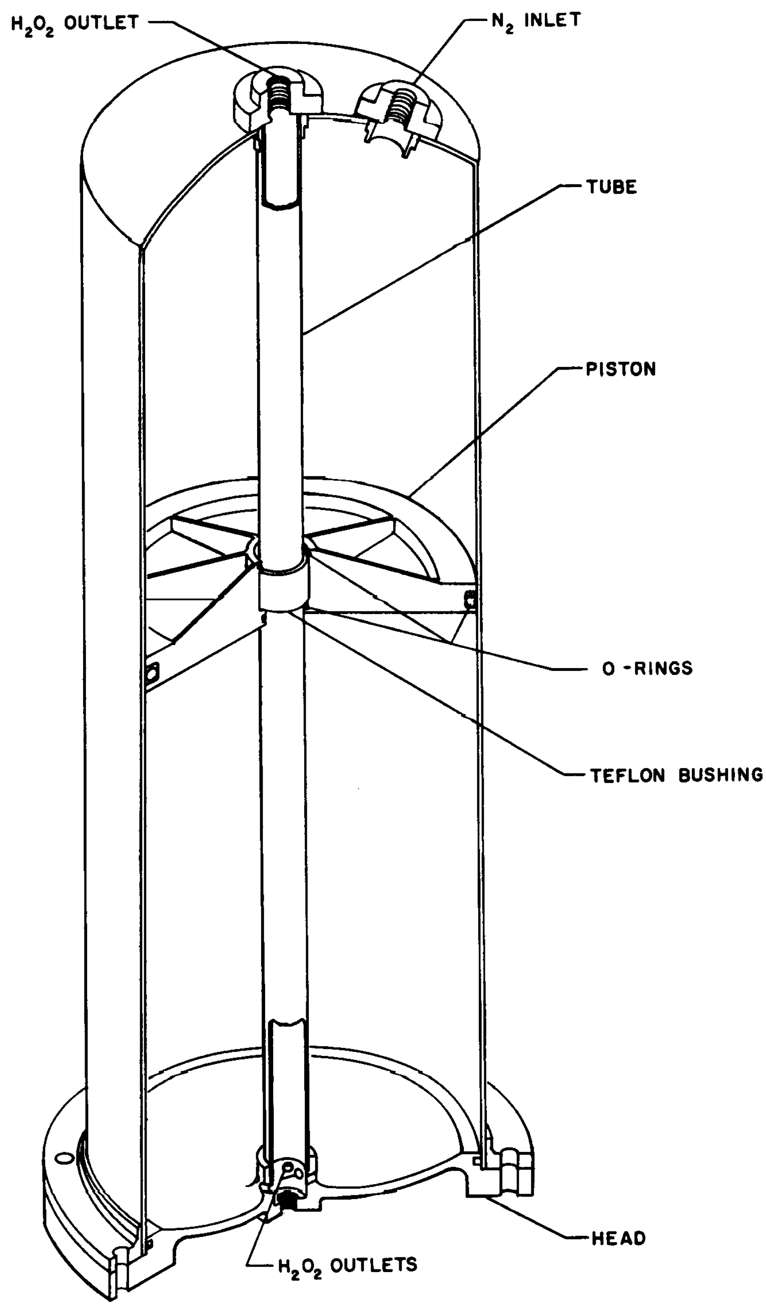
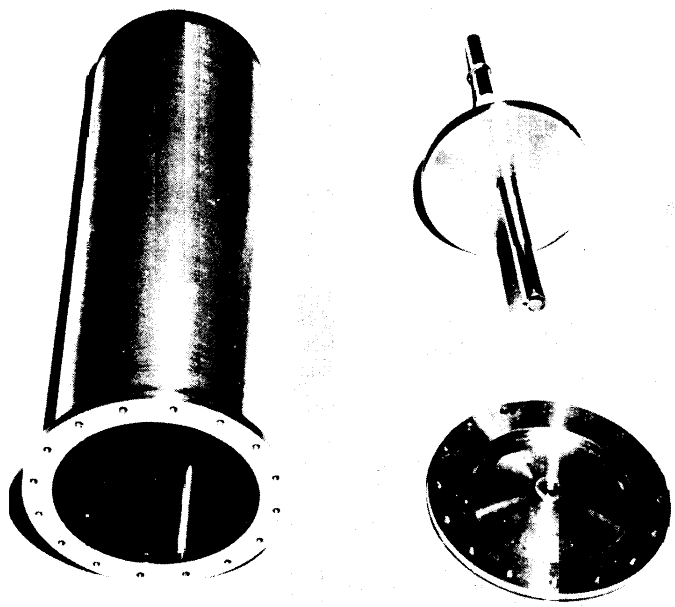
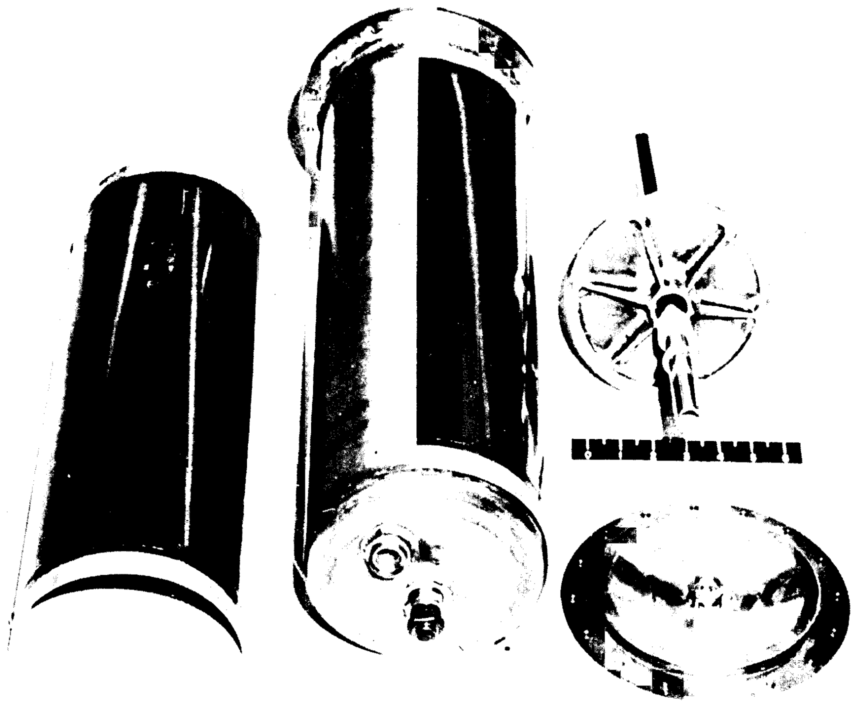


Figure 4.- Cutaway sketch of hydrogen-peroxide storage vessel.



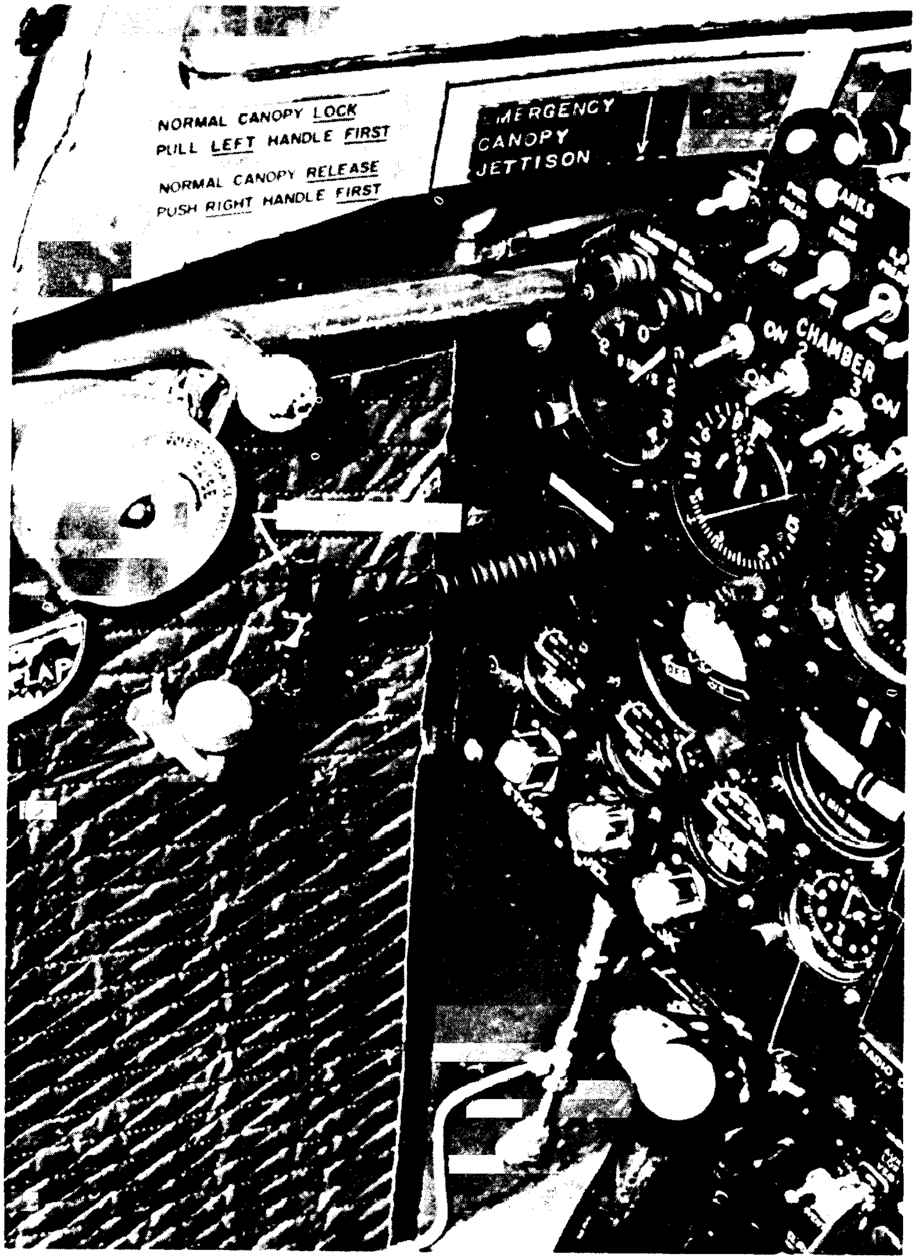
(a) Storage vessel. E-3941

Figure 5.- Major storage-vessel components.



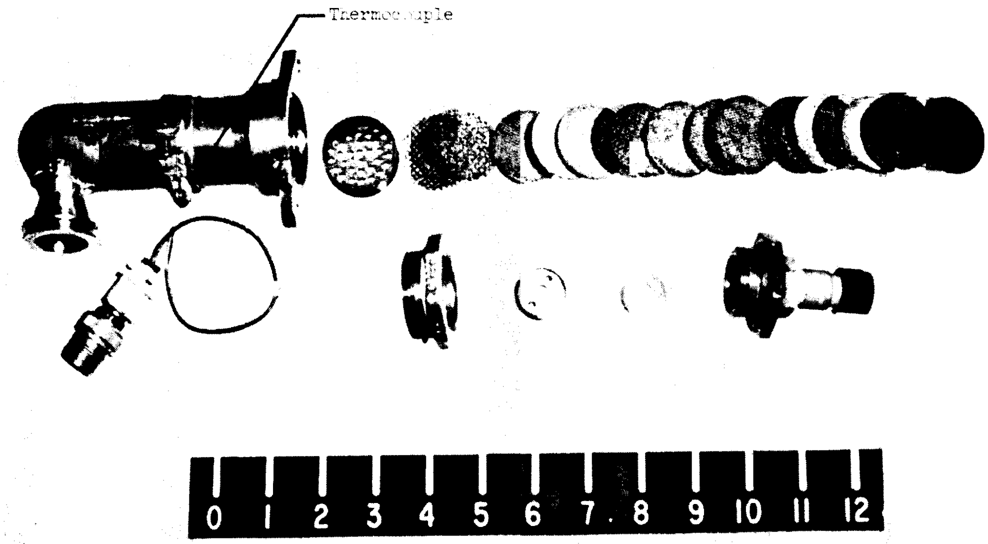
(b) Storage vessel with heater element. E-3944

Figure 5.- Concluded.



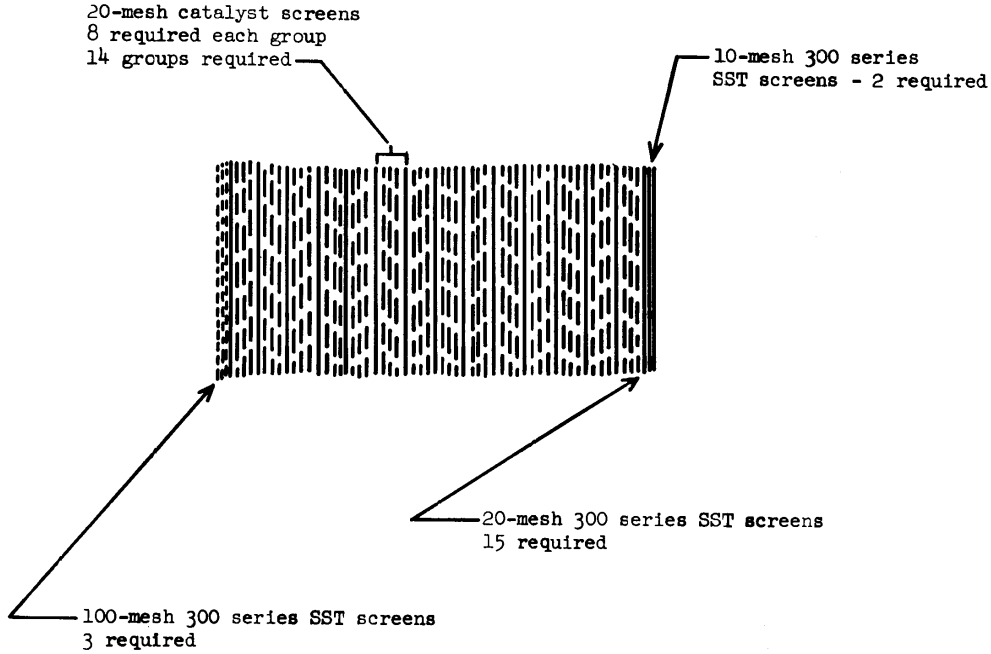
E-3940

Figure 6.- Installation of reaction-control stick in the cockpit of the X-1B research airplane.



(a) Rocket and catalyst. E-4237

Figure 7.- H_2O_2 rocket units.



(b) Catalyst screens.

Figure 7.- Concluded.

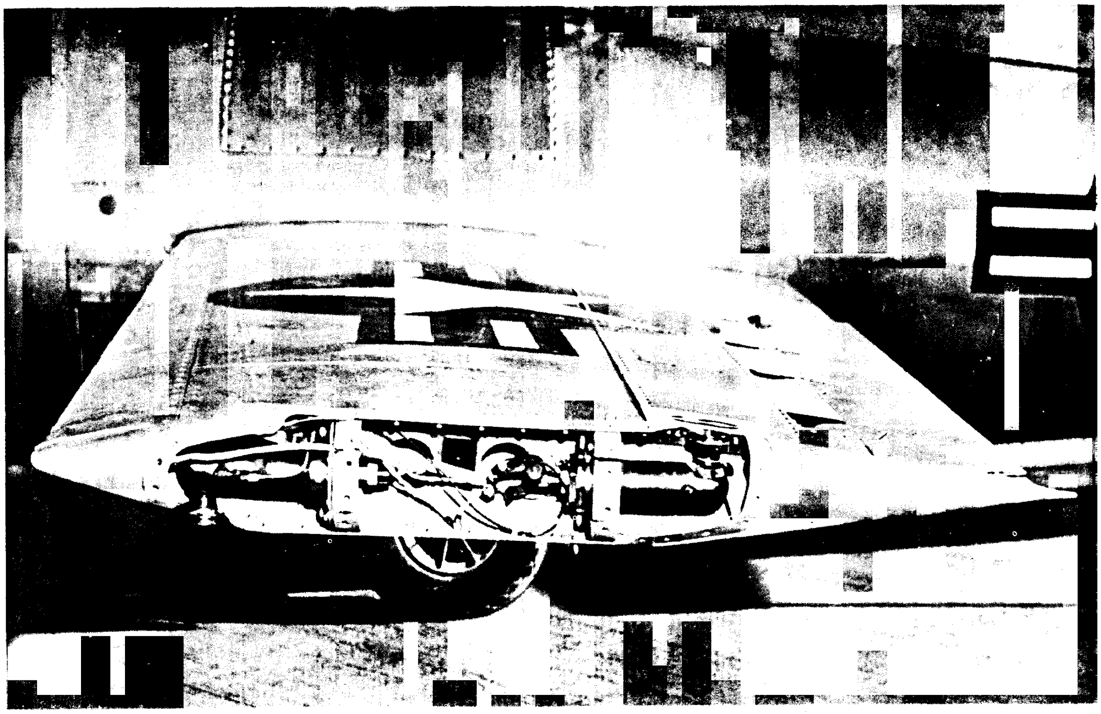


Figure 8.- Roll-rocket installation. E-3289

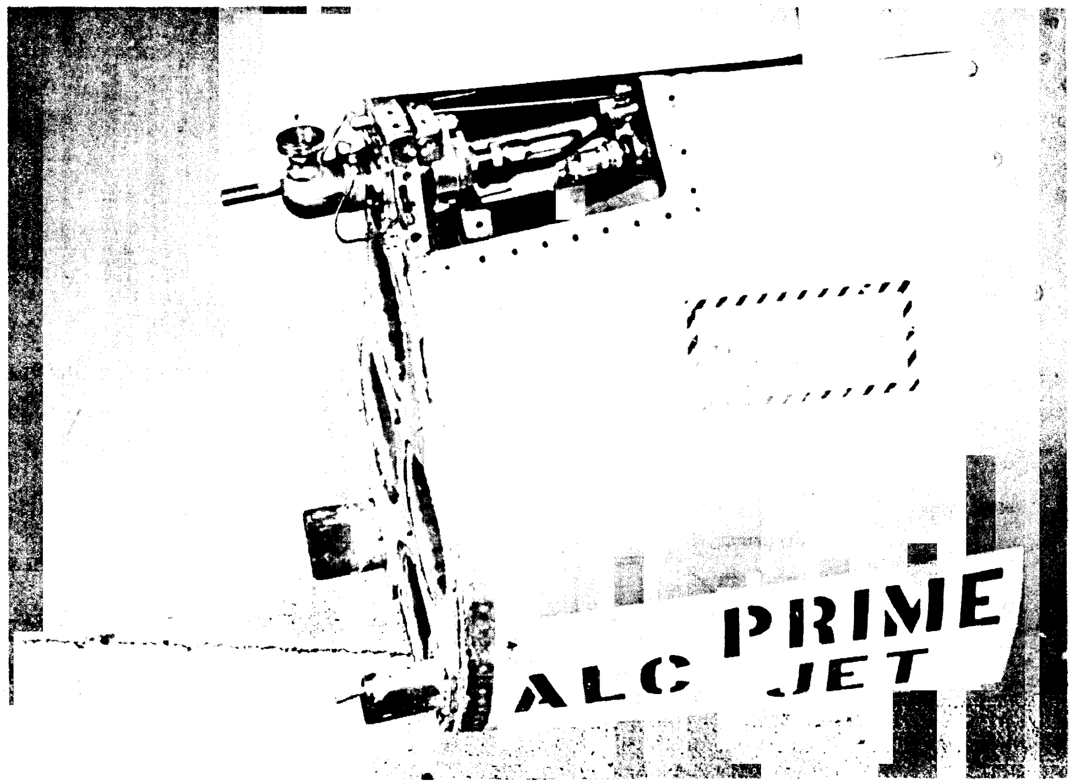


Figure 9.- Pitchup-rocket installation. E-3293

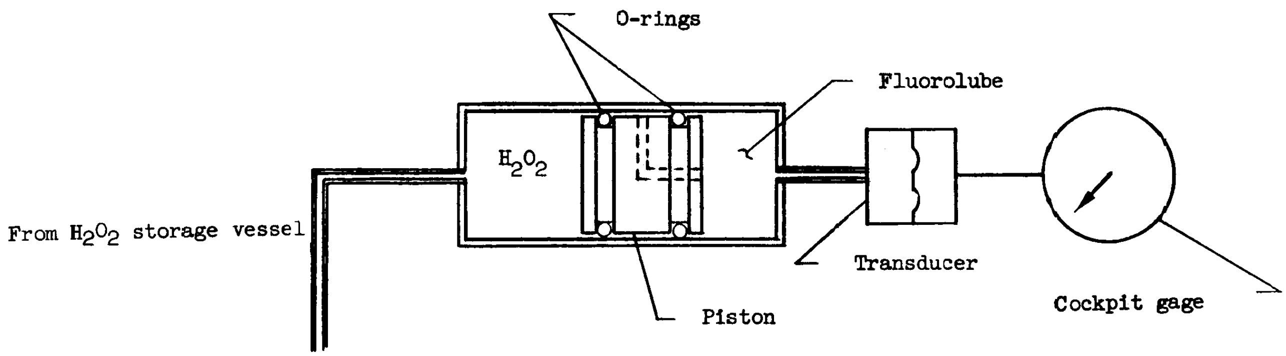


Figure 10.- Sketch of hydrogen-peroxide pressure-measuring system for the pilot's indicator.

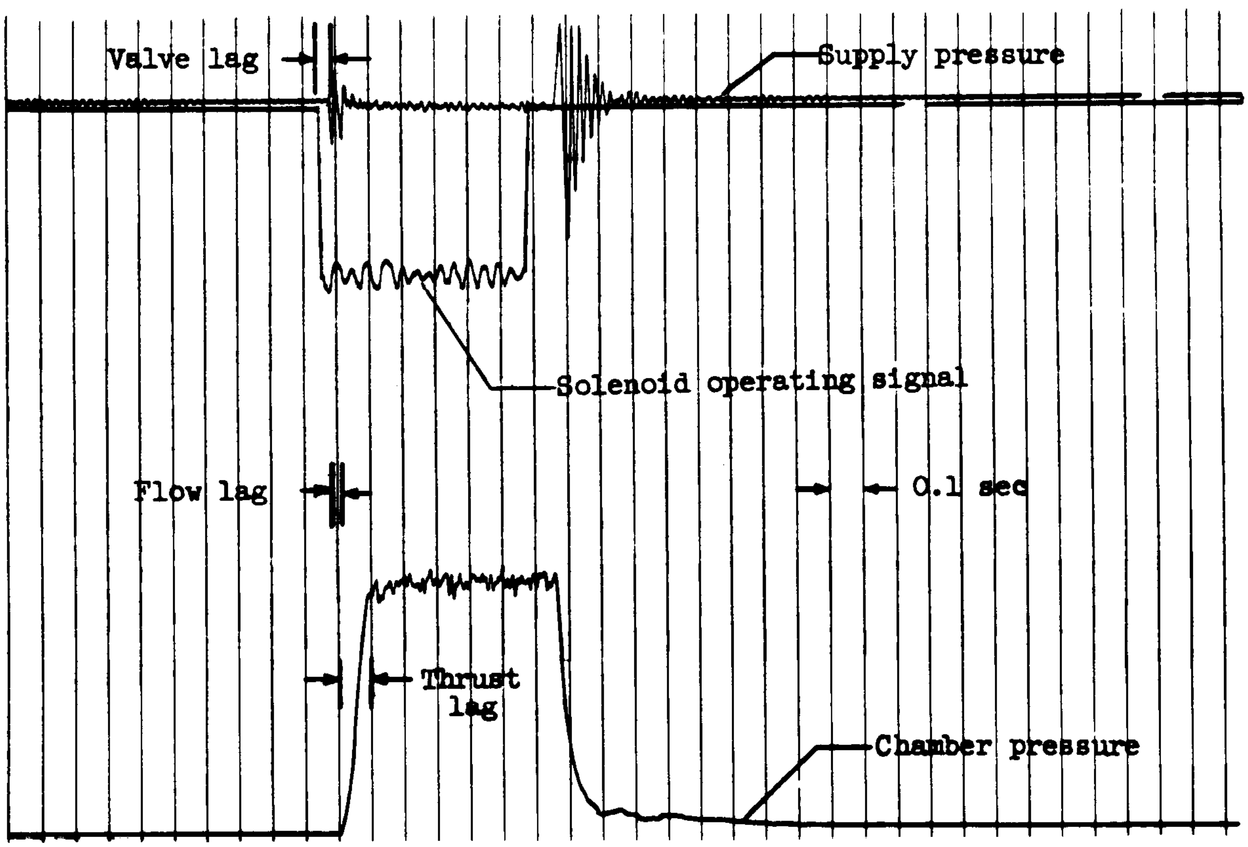


Figure 11.- Oscillograph record showing operating characteristics of hydrogen-peroxide rockets.

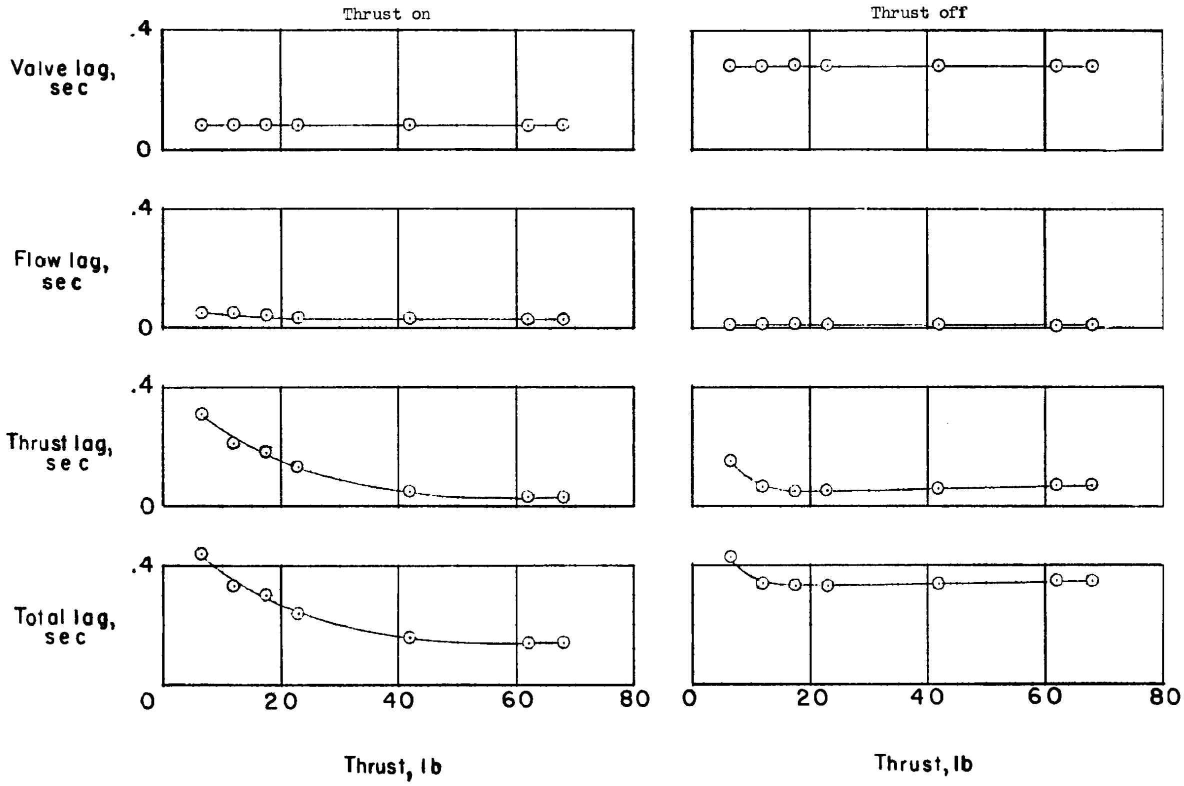


Figure 12.- Lag characteristics of hydrogen-peroxide-rocket system for various thrust levels and a type A valve.

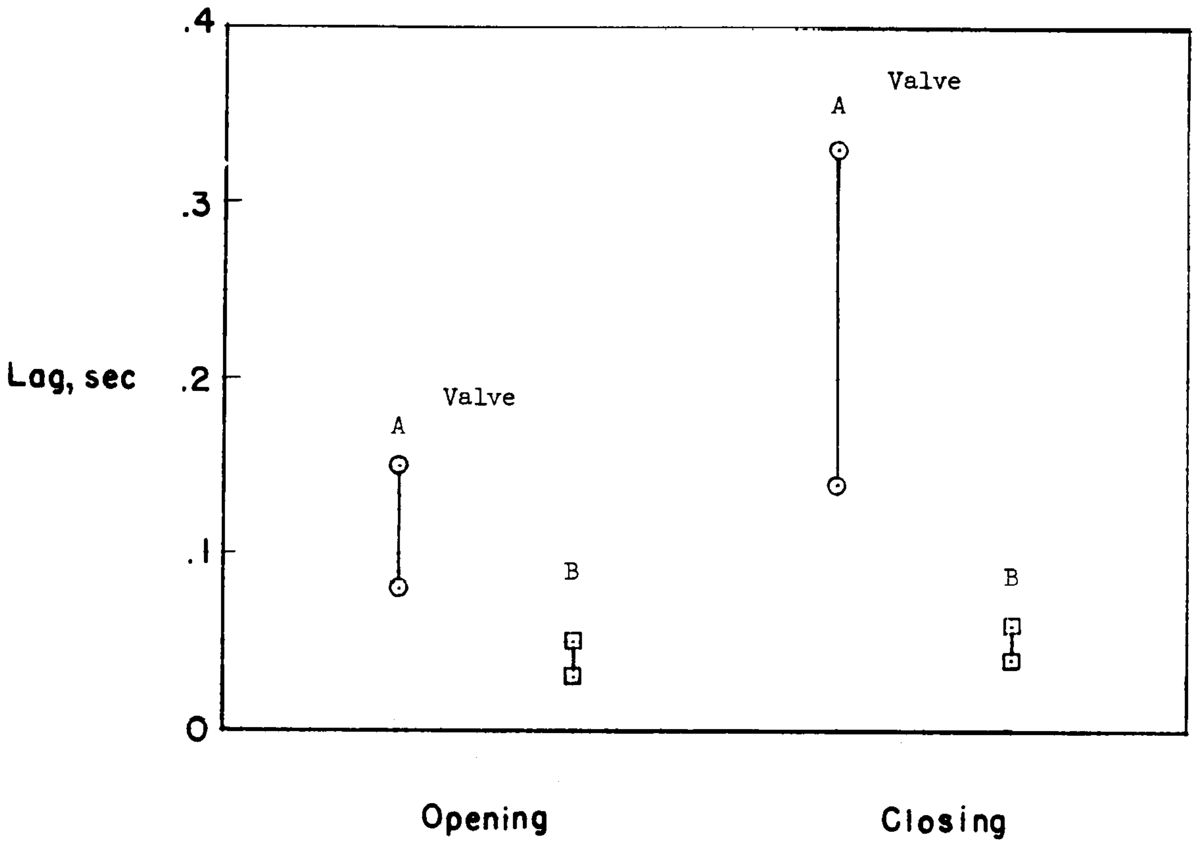
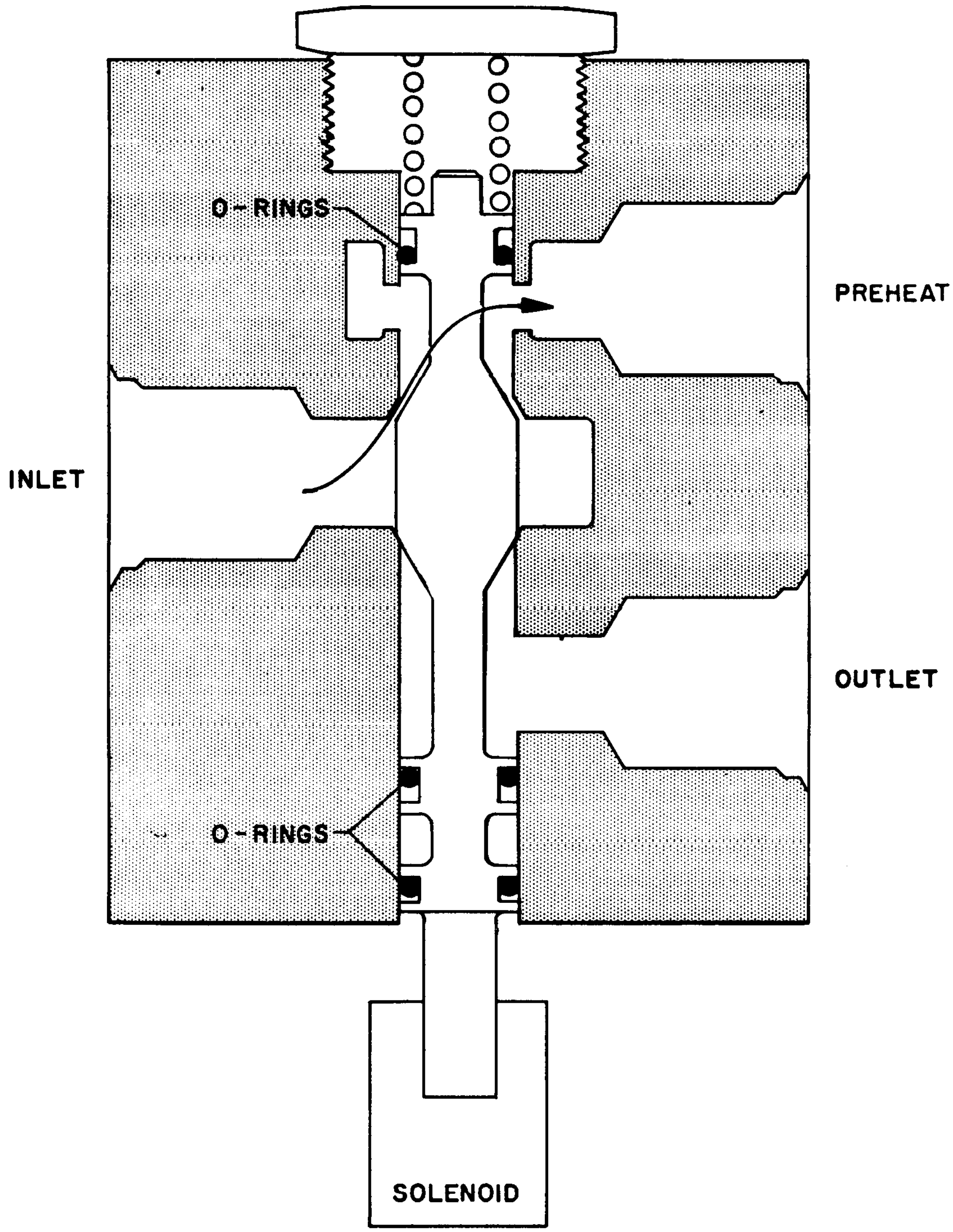
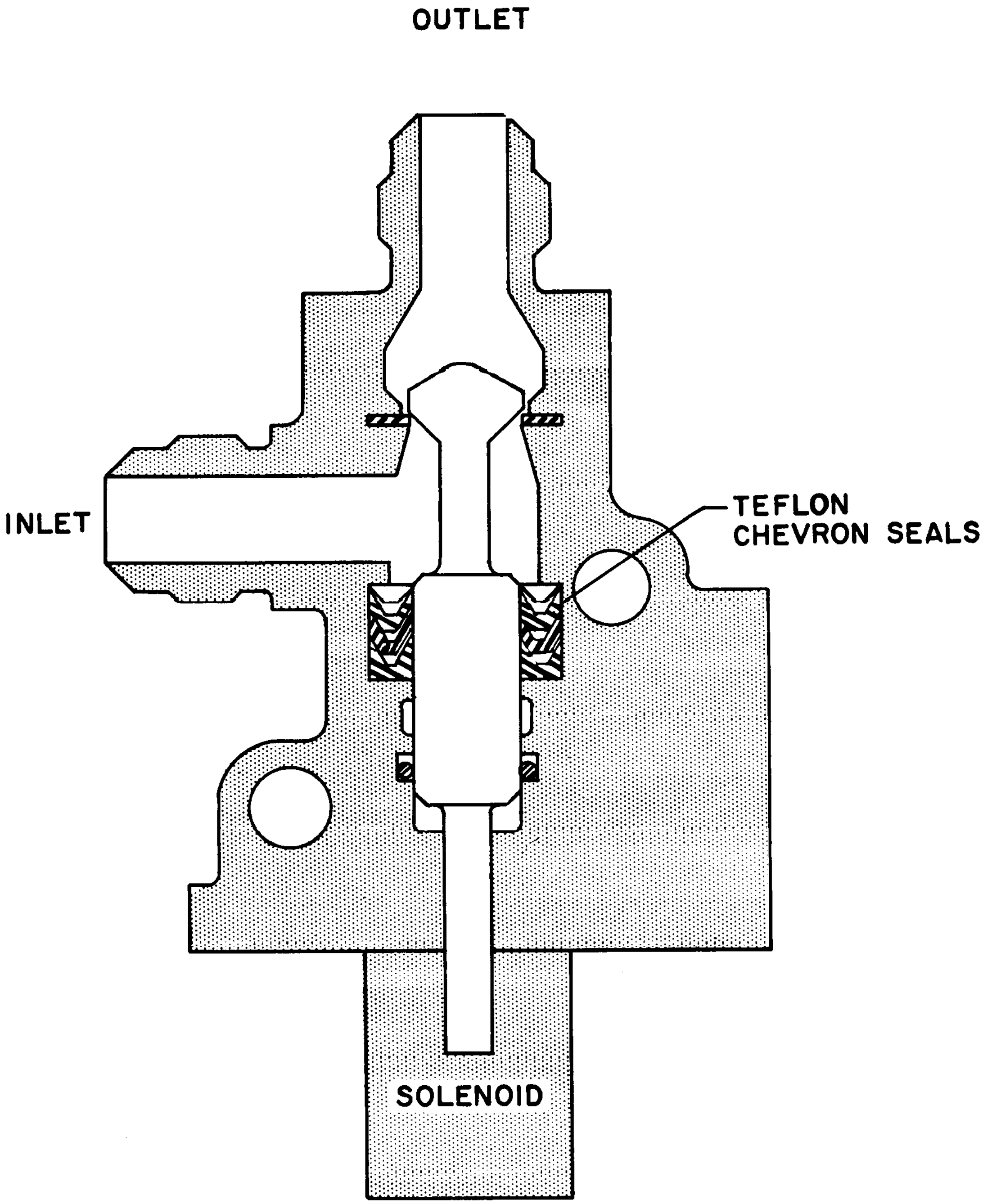


Figure 13.- Comparison of valve opening and closing time lags for type A and B valves.



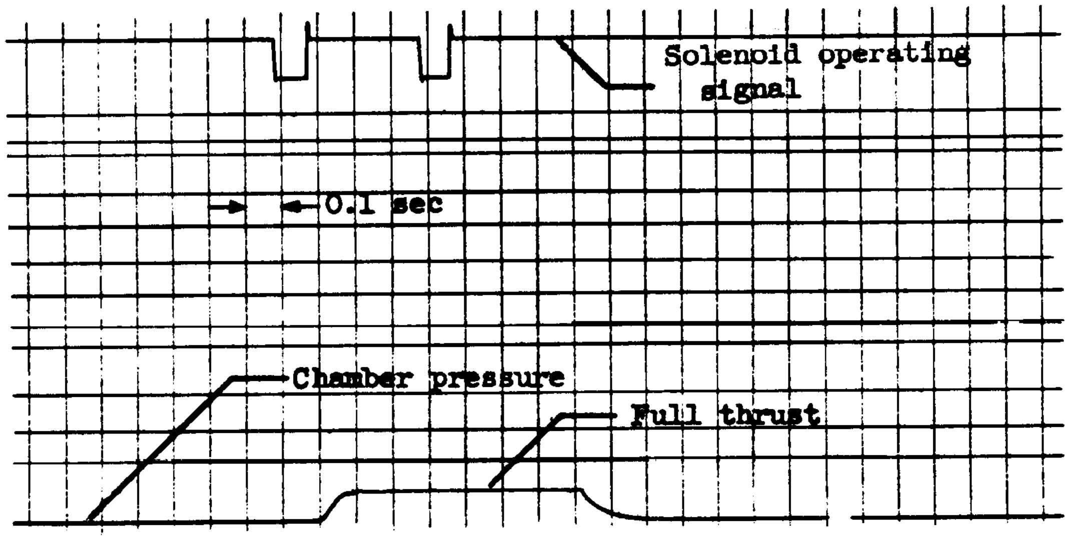
(a) Type A valve.

Figure 14.- Cutaway drawing of type A and B valves.

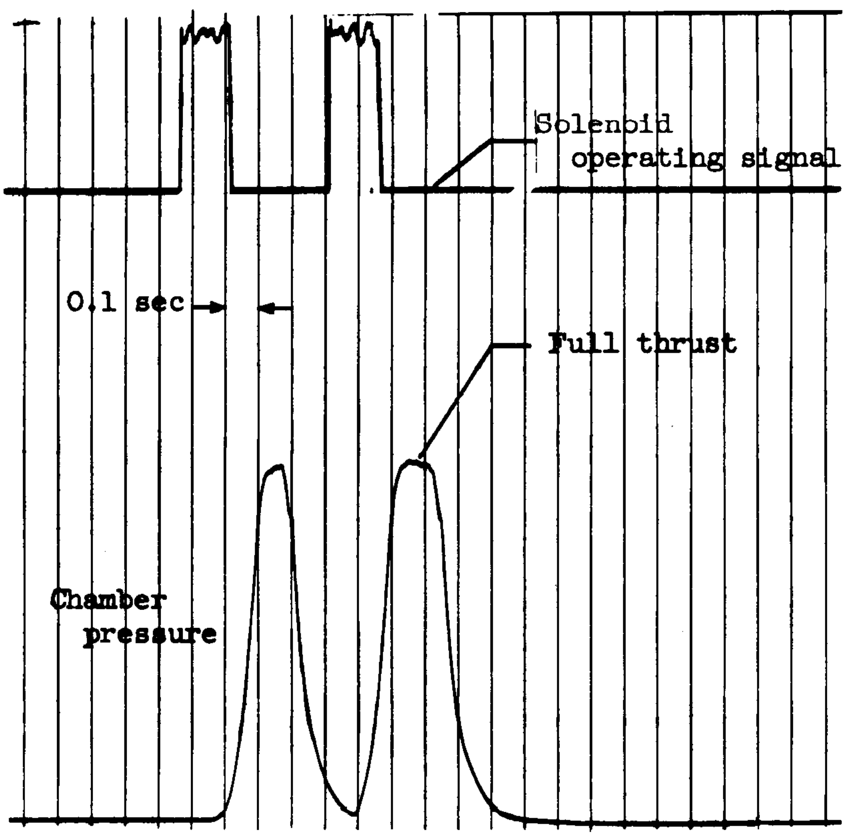


(b) Type B valve.

Figure 14.- Concluded.



(a) Valve A.



(b) Valve B.

Figure 15.- Comparison of the response characteristics of two rocket reaction-control systems with different valve lags. (Note different recording sensitivities.)